PSO MODELLING AND PID CONTROLLED OF AUTOMATIC FISH FEEDER SYSTEM

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To my beloved family and friends

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ABSTRACT

Automatic fish feeding system is an electronic device that is designed to distribute fish pellets at particular time with maximum speed regulation. There are three (3) main parts in the system which are storage, dispenser and distribution parts. A problem has been reported that the distribution part was not performed at the required speed. The main objective of this study is to improve the performance of fish feeding system by using PID controller through ARX modelling. In this study, raw data at distribution part with speed of 130 rpm, 160 rpm, 190 rpm, 220 rpm and 250 rpm were extracted and used to determine ARX equation parameters as transfer function by using PSO algorithm to optimize ARX model parameter. Validation tests used was residual analysis. The best transfer function was then used as a modelling plant in the simulation process with PID controller to determine the optimum PID parameters. Finally, implementation of a PID controller into real time system was done to verify whether this system improved or not. The PSO analysis showed that the best ARX model was at 190 rpm speed because of well superimposed predicted model with the actual system. The lowest normalized output MSE value is 0.0042015 , the lowest convergence output error value is 0.0040886, the stable pole zero map and correlation test verify the accuracy of the model reaching a 95% confidence level. ARX model parameters obtained using the PSO algorithm are two inputs (a_0, a_1) and two outputs $(b_0,\ b_1)$. The input parameter obtained is $(-0.3391, -0.4329)$ while the output parameter is $(-0.06498, -0.08334)$. The optimum PID parameter value obtained by the auto tune method is $k_p = -3.4854$, $k_i = -50.2207$ and $k_d = 0.05815$. In conclusion, the PID controller successfully improved the performance of the fish feeding system with the highest percentage of speed change of 92.59%.

ABSTRAK

Sistem pemberi makanan ikan automatik adalah peranti elektronik yang direka untuk mengagihkan makanan ikan pada masa tertentu dengan kelajuan yang maksimum. Terdapat tiga (3) bahagian utama pada sistem tersebut iaitu bahagian simpanan, dispenser dan pengagihan. Permasalahan telah dilaporkan bahawa bahagian pengagihan didapati menjana kelajuan yang tidak mencapai kelajuan yang diinginkan. Objektif utama kajian ini adalah untuk meningkatkan prestasi kelajuan mesin menggunakan kawalan PID melalui pembinaan model ARX. Dalam kajian ini, data mentah pada bahagian pengagihan pada kelajuan 130 rpm, 160 rpm, 190 rpm, 220 rpm dan 250 rpm diekstrak dan digunakan untuk menentukan parameter persamaan ARX sebagai rangkap pindah dengan menggunakan pendekatan PSO algorithma untuk mengoptimumkan parameter ARX model. Ujian pengesahan yang digunakan adalah analisis residual. Rangkap pindah yang terbaik digunakan sebagai pemodelan dalam proses simulasi dengan kawalan PID untuk menentukan parameter PID yang terbaik. Akhir sekali, mengaplikasikan pengawal PID ke dalam sistem masa nyata untuk menguji sama ada sistem pemberi makan ikan meningkat atau tidak. Analisis PSO menunjukkan model ARX yang terbaik adalah pada kelajuan 190 rpm kerana graf keluaran pemodelan PSO yang diramalkan telah bertindih dengan tindakbalas sistem sebenar dengan berkesan. Nilai keluaran normal MSE yang terendah iaitu 0.0042015, nilai ralat keluaran penumpuan yang terendah iaitu 0.0040886, peta P-Z yang stabil dan ujian kolerasi mengesahkan ketepatan model yang telah mencapai tahap keyakinan 95%. Parameter model ARX diperolehi menggunakan algoritma PSO adalah dua masukkan (a_0, a_1), dan dua keluaran $(b_0,\ b_1)$. Parameter masukkan yang diperolehi adalah $(-0.3391, -0.4329)$ manakala parameter keluaran adalah $(-0.06498, -0.08334)$. Nilai parameter pengawal PID optimum yang diperolehi oleh kaedah pelarasan automatik adalah $k_p = -3.4854,\ k_i = -50.2207$ and $k_d = 0.05815$. Kesimpulannya, pengawal PID berjaya meningkatkan prestasi sistem pemberi makanan ikan dengan peratusan perubahan kelajuan adalah 92.59%.

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LIST OF SYMBOLS AND ABBREVIATION

ARX	-	Autoregressive with exogeneous input
ARXMAX	-	Autoregressive moving average exogenous input
OE	-	Output error
BJ	-	Box Jenkins
PID	-	Proportional integral derivative
PSO	-	Particle Swarm Optimization
Kp	-	Proportional gain
Ki	-	Integral gain
Kd	-	Derivative gain
E(t)	-	Error
τ	-	Instantaneous time
Ts	-	Rise time
Tr	-	Settling time
Tp	-	Peak time
MSE	-	Mean square error
MP	-	Maximum overshoot
PWM	-	Pulse width modulation
rpm	-	Revolution per minute
USB	-	Universal serial bus
MHz	-	Mega hertz
V	-	voltage
A	-	Ampere
mA	-	Milliampere
KB	-	Kilo bytes
I/O	-	Input and output
DC	-	Direct current

PIC	-	Programable integrated circuit
LCD	-	Liquid crystal display
RC	-	Remote control
PLC	-	Programmable logic controller
Pbest	-	Personal best position met
Gbest	-	Global best position
v_k^i	-	Velocity of the i^{th} particle during k^{th} iteration
w	-	Weighting function
C1/C2	-	Cognitive and social factors
rand	-	Random number between 0 and 1
X_k^i	-	Position of the i^{th} particle during k^{th} iteration
w_{max}	-	Initial weight
w_{min}	-	Final weight
$iter_{max}$	-	Maximum iteration number
$iter$	-	Current iteration number
Iot	-	Internet of thinking

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CHAPTER 1

INTRODUCTION

1.1 Project background

Aquaculture is one of the important food production sectors contributing to the country’s economy. Asia is the largest aquaculture producer, contributing approximately 91% of aquaculture production worldwide. At present, the Malaysian aquaculture sector contributes about 13.2% of the total fish produced. Malaysia has the potential to be the major fish producer in the aquaculture industry in Asia Pacific if more local entrepreneurs venture into this aquaculture sector (Subasinghe, 2007; Alongi, 2003). In Malaysia, the fishery sector has provided employment opportunities to 89,453 fishermen and 21,507 fishermen. The consumption of fish in Malaysia was expected to increase by 14% in 2010 and the country was able to produce 89% of the fish supply for its own use (Yeoh, 2010).

In the growth of the fishery sector, the effectiveness of aquaculture management is linked to fish production rates. It is important to ensure increased quality of growth and the quantity of production of aquatic products. In ensuring the growth and enlargement of fish, fish farmers need to ensure that fish food types and frequency of fish food distribution are appropriate to the type of aquatic products. The method of food distribution to each fish ponds or cages plays an important role in maximizing profitability for aquaculture entrepreneurs. The proper way of distributing food enables the growth and expansion of fish in the pond and cage. This is the motivation of the study in improving effectiveness and stability of automatic fish feeder systems. The development of this system is aimed to overcome problems that arise in the operation of current feeder machines in the market which is ineffective and has unstable power systems.

Based on innovation and technology today, several techniques have been developed by researchers including direct and indirect system. A lot of ideas have come out to make the fish feeding system more effective and powerful. In this project, controller system will be designed to improve the efficiency and stability of fish feeding system.

1.2 Problems statement

Nowadays, robots or automated machines are widely used to assist manpower in most industries. In aquaculture, technologies have been developed to increase the efficiency of manpower such as in fish feeding machine. This machine is usually developed by a combination of mechanical and electronics systems. The most important electronic part in this system is Direct Current (DC) motor, used as an actuator to spread the fish pellets into targeted area. Many researchers have developed an automatic fish feeding system. Currently feeding machine was develop using microcontroller such as Programmable Integrated Circuit (PIC), Arduino, Raspberry Pi and so on. However, this system still uses on-off type of controller system or open loop system. An on-off controller system simply drives the manipulated variable from fully 'ON' and fully 'OFF' depending on the position of the controlled variable relative to the set point. This system shows a response that does not reach the desired target which undershoot or overshoot response.

In order to solve this problem, it is proposed to conduct the experiments and simulations on existing fish feeding machines to study the behaviour of the distribution part system. Based on experimental data, an ARX model Particle Swarm Optimization (PSO) technique is applied and the system is improved by applying the PID controller.

1.3 Research objective

The objectives of this research are as follows:

i. To model the behaviour of fish feeding machine by using System Identification (SI) technique.
ii. To simulate ARX model with PID controller by optimizing the PID parameters.
iii. To validated experimentally Fish Feeder Machine performance.

1.4 Scope of the study

The scopes of the project are divided into several parts including the simulation and experimental testing:

i. Raw data extraction of voltage as an input and speed as an output from experimental process in order to be used in modelling process using PSO technique in MATLAB environment.
ii. Apply PSO algorithm to optimize the parameter of ARX model.
iii. Simulate PID controller by optimizing PID gains parameter using the auto tuner method in Matlab/Simulink environment with 20 times of trials.
iv. Implement the PID controller through experimental processes on fish feeder machine using Arduino board and Matlab/Simulink interface.

1.5 Thesis organisation

This thesis comprises of five chapters. Detailed explanation is discussed respectively in every section as follow:

Chapter 2: A comprehensive literature review includes automatic fish feeder system, modelling process, PSO algorithm and selected controller which have been presented from previous researchers. Furthermore, important elements involved in this study is also presented including system identification, MATLAB software, Arduino microcontroller and control system characteristic.

Chapter 3: This chapter represents the methodology of this study to accomplish the objectives. The details about plant description and experiment design are discussed in this section. Furthermore, the process of PSO is explained to be used in the parameter optimization.

Chapter 4: The results and discussion are provided in this chapter. The simulations of the proposed power controller are tested to ensure its validity. The detaileds analysis of PSO result is also disscused based on ARX model and PID controller parameter optimization. Furthermore, comparison of the speed performance output response with and without applying PID controller is also explained.

Chapter 5: The conclusion of the research is summarised in the final chapter. The recommendations for future research are also listed in this section.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explains about the fundamental and previous study related to automatic fish feeder system, system identification, particle swarm optimization (PSO) technique process, PID controller, MATLAB/Simulink environment, Arduino microcontroller, modelling structure and control system characteristic.

2.2 Definition of automatic fish feeder system

Automatic fish feeder system is an electronic device that has been designed to distribute the right amount of fish pellets at a specified time. Basically, the fish feeder machine has three main parts which are the tank, dispenser and distribution parts. The tank is the part for storing fish pellets. The part of dispenser is to flow out the fish pellets from the tank to the distribution area. The distribution part pushes out the fish pellets into the fish pond or cage. In general, two basic concepts which are fixed and mobile conceived the automatic feeder (Zulkefly, 2010). Nowadays, many overseas aquaculture entrepreneurs have already used the system of machine during aquaculture production process at pond and cage of fish since 1990 in Belgium, the Unites States, Italy and Thailand (John, 2012). In addition, this system also demonstrates the capability in the fish farming field in a long term. However, the technology and innovation of fish feeder machine is still a new development and research work is still ongoing in Malaysia

Generally, fish is normally fed by manual, semi-automatic and automatic feeding as shown in Figure 2.1. However, the latter has been seriously put into conversation by many aqua-culturists and researchers as it applies technological approaches in a multi-scale manner. An automatic fish feeder category can be classified by the type of energy used to dispense pellets which is hydraulic, pneumatic and electric energy. The category can also be classified by determining the method of delivering the fish pellets where the feeder may automatically be in static state or function as a mobile unit (Shaari, 2011). By using an automatic fish feeder system, fish farmer will have better management by scheduling their own fish feeding time (Patrick, 2009). The simple automatic fish feeder system employed is able to dispense the fish pellets of desired amount at a specified speed.

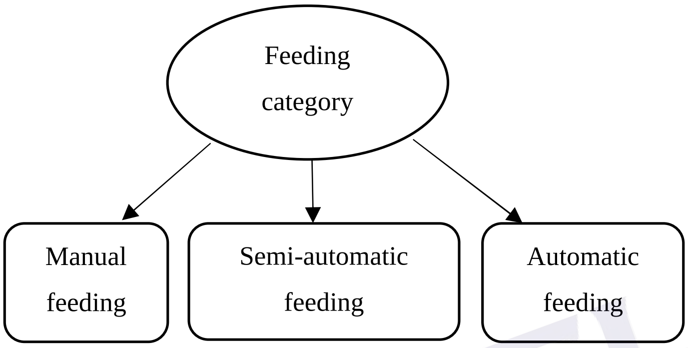

Figure 2.1: Fish feeding category (Shaari, 2011)

Labour are required to distribute feed to the manual or semi-automatic except the fully automatic feeding. Feeding schedule on time could be achieved by using the timer (Shaari, 2011).

2.3 System Identification

System identification is a method of using the input and output data of the system to develop the mathematical model of the system which is being widely applied to various fields of production and life (Fu et al., 2013). System identification has been developed since years ago where there are several different opinions on the system identification. Generally, the process of system identification involves the extraction, analysing and identifying mathematical model from raw data measured through experimental process.

System identification is a process of developing the model of dynamic system by using the input and out data. According to Othman & Kamal (2009), system identification is the art in science of construction a mathematical relationship of measured data which generate the mathematical models. The model of the system was translated in the form of transfer function. System identification is probably the most important step in characterizing the behaviour of the system, controller development or improvise system performance (Burgos et al., 2005).

The purpose of construction model of the system is to gain knowledge and insights about the system behaviour (Othman & Kamal, 2009). Moreover, Huang (2017) state that, the main purpose of modelling is to understand the behaviour of a system and have prediction of its performance for fault diagnosis. The system can be analysed through the model obtained as the model constructed represent the accurate behaviour of real system. Modelling of any system can facilitate for the study effect of different component and make prediction of the system's behaviour (Patil & More, 2014). Moreover, model of given system also important to control the system efficiently and predict the responses on reference signal not only for the purpose of understanding the system behaviour (Eshkabilov et al., 2013). Modelling process of complex system with the limited knowledge can be difficult. Thus, according to Jahaya et al (2011), there is an empirical approach has been introduced for modelling which is system identification.

According to Zadeh (1962), identification is on the basis of the input and output data in order to determine the equivalent model from a group of given models for the system under experiment. Subsequently, according to Eykhoff (1974), further identification problems can be summed up as a kind of calculus which represents the essential characteristics of the objective system by a model and the understanding of the objective system which can be expressed as useful forms using this method. The definition of identification proposed by Ljung (1978) is more specific in which identification contains three elements which are data, models and standards. The identification is in accordance with criterion, and finally we select a model which fits the best data from a set of models. However, according to Ding (2011), system identification consists of designing an appropriate input signal, using experimental input and output data, selecting a class of models, constructing an error criterion function and determining a model that fits the best data by optimization methods. This comprehensive definition emphasizes the design of the input signal strongly in system identification and optimization methods.

According to Hussin (2011), there are three fundamental steps in developing the model which is the input and output data, model structure and identification method. A model is described by transfer functions, differential equations, state-space equations, dynamical model can be represented either in continuous or discrete time.

Analysis input and output data of either time or frequency can be used to determine continuous time and discrete time transfer functions, state space models and process model (Lai et al., 2012).

The system identification loop as in Figure 2.2 is divided into four (4) main processes to build a model for a system. It starts with experiment for collecting data, model selection, estimation and validation the model (Hassan et al., 2007). The validation test in general, use residual analysis technique to find the best model. If the model is not accepted, the process will refer to previous step of selecting model structure and parameter model estimation. Also, it can be fault at the first stage when the data at recording process. It will a repetitive process until the model is accepted when it meets the requirement.

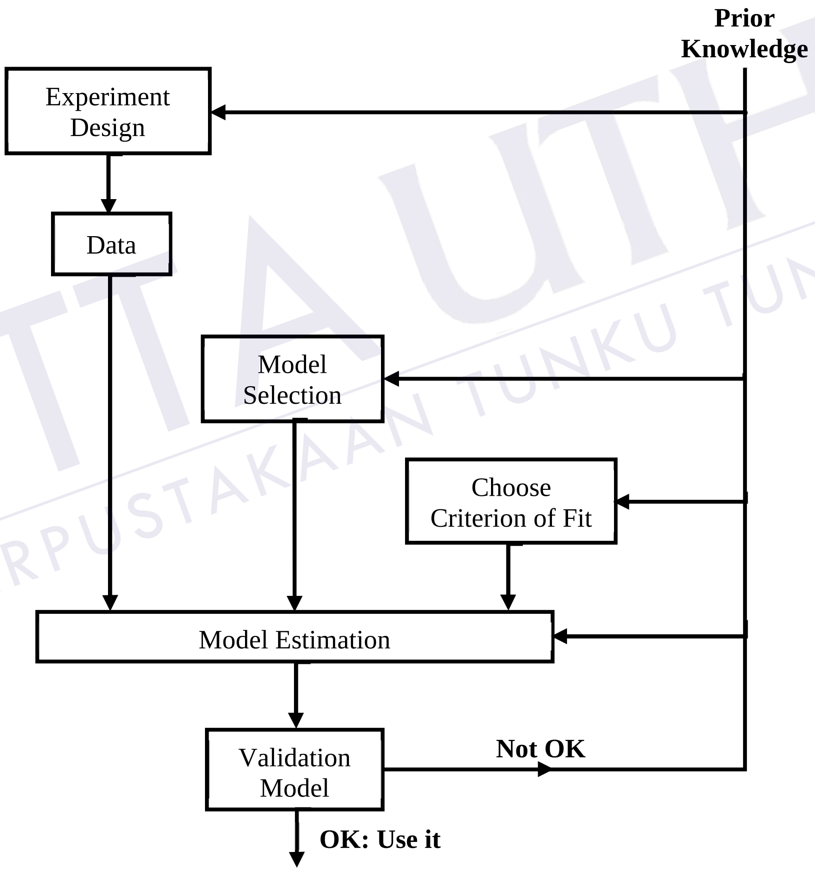

Figure 2.2: The system identification loop (Ljung, 1978)

2.4 Model structure

Parametric system identification is the process of fitting of model parameters to a pre-selected model based on input and output data. The qualitative information by nonparametric identification can be used to select the proper model structure. Parametric identification can be seen as identifying the optimal parameters of a filter of pre-determined order. The parameter identified by system identification is the best approximation to the real model parameters with respect to a certain criterion such as the minimum of the norm between the estimate and residuals.

Parametric methods are separated into Grey-Box estimation where some of the parameters are known and Black-Box estimation where none of the parameters are known (Ljung, 1978). Almost all of the parametric models can be described as variant of the general linear parametric model as given in Figure 2.3.

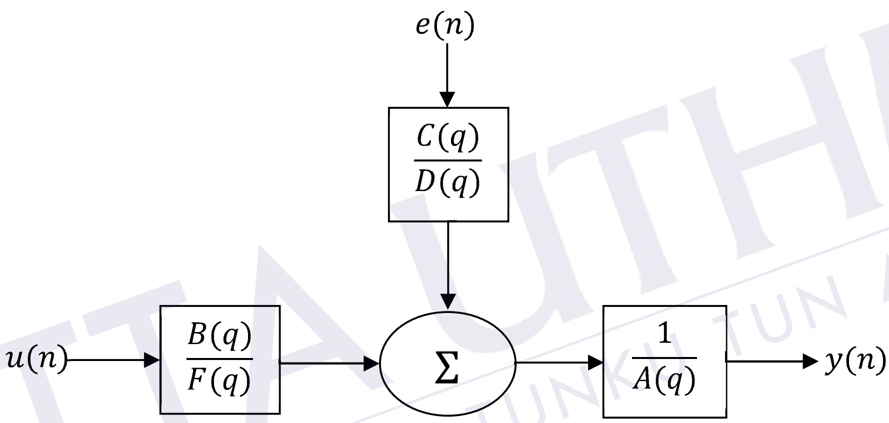

Figure 2.3: General linear parametric model

Where the q is the discrete shift operator; *u(n)* is the input, *e(n)* is the noise and disturbance, *y(n)* is the output and *A(q), B(q), D(q)* and *F(q)* are finite difference equations (Salleh et al., 2009).

2.4.1 Autoregressive with exogeneous input model

Autoregressive with exogeneous input (ARX) model structures occur when C(q), D(q) and F(q) in Figure 2.3 is equal to 1. Thus, the general linear polynomial model is reduced. Figure 2.4 shows the ARX model structure.

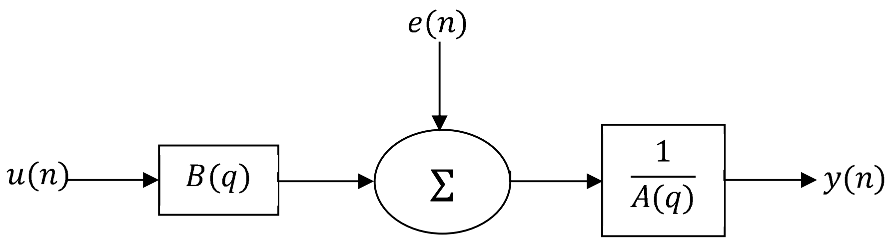

Figure 2.4: The ARX model structure

The following equation describes an ARX model.

$$A(q)y(n) = q^{-k}B(q)u(n) + e(n) = B(q)u(n-k) + e(n) \tag{2.1}$$

The estimation of the ARX model is the most efficient of the polynomial estimation methods because it is the result of solving linear regression equation in analytic form (Yusoff et al., 2012).

2.4.2 Autoregressive moving average exogeneous input model

Meanwhile, autoregressive moving average exogeneous input (ARMAX) model is developed when *D(q)* and *F(q)* in Figure 2.3 is equal to 1. Figure 2.5 shows the signal flow from the ARMAX model structure.

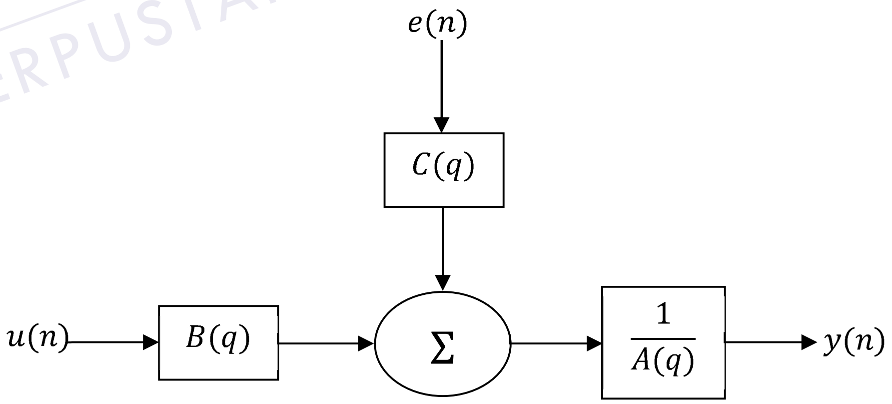

Figure 2.5: The ARMAX model structure

The following equation describes the ARMAX model.

$$A(q)y(n) = q^{-k}B(q)u(n) + C(q)e(n) = B(q)u(n-k) + C(q)e(n) \tag{2.2}$$

Unlike the ARX model, the system structure of an ARMAX model includes disturbance dynamics. ARMAX models is used in case of known disturbance in the process of system, such as at the input (Chao et al., 2005).

2.4.3 Output error model

As *A(q)*, *C(q)* and *D(q)* in Figure 2.3 equal to 1, the general linear polynomial model reduces to the Output Error (OE) model. Figure 2.6 shows the OE model structure.

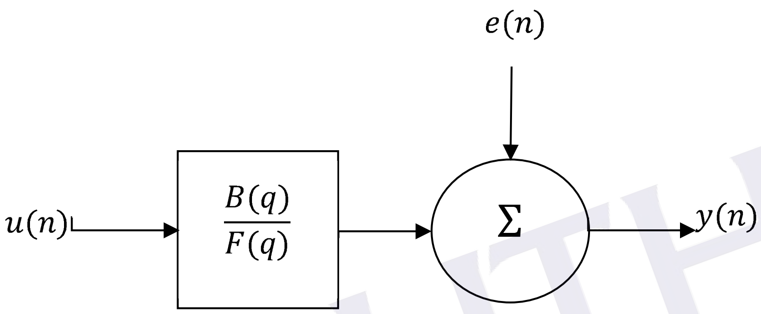

Figure 2.6: The OE model structure

The following equation describes the OE model.

$$y(n) = \frac{q^{-k}B(q)}{F(q)}u(n) + e(n) = \frac{B(q)}{F(q)}u(n-k) + e(n) \tag{2.3}$$

The output-error model describes the system dynamic separately. The output-error does not use any parameters for modelling the disturbance characteristics.

2.4.4 Box Jenkins model

If *A(q)* in Figure 2.3 is equal to 1, the general linear polynomial model reduces to the Box Jenkins (BJ) model. Figure 2.7 shows the model structure of the BJ model.

REFERENCES

Alongi, D.M., Chong, V.C., Dixon, P., Sasekumar, A. & Tirendi, F. (2003). *The influence of fish cage aquaculture on pelagic carbon flow and water chemistry in tidally dominated mangrove estuaries of Peninsular Malaysia, Malaysia.* Marine Environmental Research. 55, pp. 313-333.

Abdul-Rahman, O,. Munetomo, M., & Akama, K. (2011). *An Improved Binary-Real Coded Genetic Algorithm for Real Paramter Optimization.* {roceedings of the 2011 3rd World Congress on Nature and Biologically Inspired Computing. NaBIC 2011, 149-156.

Aleed, Y. H. & Tutunji, T. A. (2017). *Re-Engineering and System Identification*. pp. 151–156, 2017.

Angeline, P. J. (1998). *Using selection to improve particle swarm optimization*. in Proc. IEEE Int. Conf. Evol. Comput., Anchorage, AK, May 1998, pp. 84–89.

Andrijic, Z.U., Bolf, N. & Rolish, T. (2011). *Optimizing Configurable Paramters of Model Structure Using Genetic Algorithms.* REDI International Interdisciplinary Journal of Young Scientists from the Faculty of Textile Technology TEDI, 1(January), 49-54.

Angelova, M. & Pencheva, T. (2011). *Tuning Genetic Algorithm Parameters to Improve Convergence Time.* International Journal of Chemical Engineering, 2011.

Bai, Q. (2010). *Analysis of Particle Swarm Optimization Algorithm*. Comput. Inf. Sci., vol. 3, no. 1, pp. 180-184,2010.

Bi, D.Q., Zhang, X.A., Yang, H.H., Yu, G.W., Wang, X.H., and Wang, W.J. (2007). *Correlation analysis of waveforms in non-saturation zone-based method to identify the magnetizing inrush in transformer.* IEEE Trans. Power Del., 22(3):1380-1385

Beni, G. & Wang, J. (1989), *Swarm Intelligence in Cellular Robotics Systems*. Proceeding of NATO Advanced Workshop on Robots and Biological System.

Toscana, Italy, June 26-30, 1989 (pp.703-712).

Blondin, James. (2009). *Particle Swarm Optimization: A Tutorial*.

Burgos, M., Getto, D., & Berne, P. (2005). *System IdentificTION BY Experimental Data Processing, Application to Turbulent Transport of A Tracer in Pipe Flow*. International Nuclear Altantic Conference-INAC 2005.

Chao-Ming, H., Chi-Jen, H., and Ming-Li, W. (2005). *"A particle swarm optimization to identifying the ARMAX model for short-term load forecasting,"* IEEE Trans. Power System., vol. 20, no. 2, pp. 1126–1133, 2005.

Curtis, A., R. (1991). A*n Application of Genetic Algorithms to Active Vibration Control*. Journal of Intelligent Material Systems and Structures, 2(4), 472-481.

Ding, F. (2011). *System identification, Part A: Introduction to the identification*. Journal of Nanjing University of Information Science and Technology: Natural Science Edition, vol. 3, no. 1, (2011), pp. 122.

Dorigo, M., Birattari, M. & Stutzle, T. (2006). *Ant Colony Optimization: Artificial Ants as a Computational Intelligence Technique*. IEEE Computational Intelligence Magazine, 28-39.

Dwivendi, Y. & Kumar, V. (2017). *Dynamic Stability Improvement of Alkali Fuel Cell Integrated System Using PSO Optimized PID Control Design*. 2017 Recent Dev. Control. Autom. Power Eng., vol. 3, pp. 3–8, 2017.

El-Gamma, A., A. & El-Samahy, A., A. (2009). *A Modified Design of PID Controller for DC Motor Drives Using Particle Swarm Optimization (PSO) algorithm*. IEEE, pp. 419-424.

Eshkabilov, S. & Madirimov, E. (2013). *Mathematical Modelling and System Identification Aspects of Heat Flow Process Nside a Closed Box*. pp 1-13.

Eykhoff, P. (1974). *System Identification:Parameter and State Estimation*. John Wiley & Sons, 1974, pp. 555.

Fu, L. & Li, P. (2013). *The research survey of system identification metho*d. Proc. - 2013 5th Int. Conf. Intell. Human-Machine Syst. Cybern. IHMSC 2013, vol. 2, pp. 397–401, 2013.

Gautam, Bijaya. (2010). *Spectral Estimation of Electroencephalogram Signal using ARMAX Model and Particle Swarm Optimization*. Texas:Lamar University.

Hasim, H. N., Ramalingam, M., Ernawan, F. & Puviarasi, R. (2017). *Developing fish feeder system using Raspberry Pi*. Proc. 3rd IEEE Int. Conf. Adv. Electr. Electron. Information, Commun. Bio-Informatics, AEEICB 2017, pp. 246–250, 2017.

Hassan, M.M., Aly, A.A. & Rashwan, A.F. (2007). *Different Identification Methods with Application to a DC Motor 1.* System Identification Procedures, 35(6), pp 1481-1493.

Huang, Y., Gao, L., Yi, Z., Tai, K., Kalita, P., Prapainainar, P. & Garg, A. (2017). *An Application of Evolutionary System Identification Algorithm in Modelling of Energy Production System. Measurement:* Journal of the International Measurement Confederation, 114 (August 2017), pp 122-131.

Hussein, M.S., Azuwir, M.N. & Zaiazmin, Y.N. (2011). *Modelling and Validation of Brushless DC Motor.* 2011 4th International Conference on Modelling, Simulation and Applied Optimization, ICMSAO 2011, pp 0-3.

Jahaya, J., Nawawi, S.W. & Ibrahim, Z. (2011). *Multi Input Single Output Closed Loop Identication of Two Wheel Inverted Pendulum Mobile Robot.* In Research and Developmtn (SCOReD), 2011 IEEE Student Conference on IEEE., pp138-143.

Jamian, J. J., Mustafa, M. W., Mokhlis, H. & Abdullah, M. N. (2012). *Comparative study on Distributed Generator sizing using three types of Particle Swarm Optimization*. Prof.- 3rd Int. Conf. Intell. Syst. Model. Simulation, ISMS 2012, pp. 131-136, 2012.

Jawa, Sara, N., A. (2011). *An ARMAX Model of QAD BDT 921 Heat Exchanger Identification.* Batu Pahat: Universiti Tun Hussein Onn (UTHM).

Jin, H.P., Su, W.S. & Lee, I.B. (1998). *An enhanced PID control strategy for unstable processes. Automatica*, 34(1998) 751-756.

Jimenez, M.J., H. Madsen, K.K. & Andersen. (2008). *Identification of The Main Thermal Characteristics of Building Components Using MATLAB* .Building and Environment, 170-180.

John, S. L. & Paul, C.S. (2012). *Aquaculture Farming Aquatic Animals and Plants (Second Edition).* Australia.

Johansson, R. (1993). *System Modeling and Identification.* Englewood Cliffs, New Jersey: Prentice-Hall.

Kakhki, H. A. and Moghaddam, R. K. (2015). *Using PSO to optimize the mathematical model of li-ion battery.* 2nd Int. Congr. Technol. Commun. Knowledge, ICTCK 2015, no. Ictck, pp. 197–200, 2016.

Kennedy, J. and Eberhart, R. (1995). *Particle swarm optimization.* in Proc. IEEE Int. Conf. Neural Netw., vol. 4, Nov./Dec. 1995, pp. 1942–1948.

Kobayashi, T. and Otsu, N. (2009) "*Three-way Auto Correlation Approach to Motion Recognition*," Pattern Recognation Letters, 30(3), pp. 212-221.

Lai, W.K., Rahmat, M.F. & Wahab, N.A. (2012). *Modelling and Controller Design of Pneumatic Actuator System with Control Valve.* International Journal on Smart Sensing and Intelligent Systems, 5(3), pp 624-644.

Ljung, L. (1978). *Convergence analysis of parametric identification methods*. IEEE Trans. on Automatic Control, vol. 23 no. 5, Oct. 1978, pp. 770-783.

Lin, M.H., Tsai, J.F. & Lee, L.Y. (2013). *Ant Colony Optimization for Social Utility Maximization in a Multiuser Communication System.* Mathematical Problems in Engineering, 2013.

Marco, D., Mauro, B. & Thomas, S. (2006). *Ant Colony Optimization.* IEE computational Intelligence Magazine, i(4), 28-39.

Noor, M. Z. H., Hussian, K., Saaid, M. F., Ali, M. S. A. M. & Zolkapli, M. (2012). *The Design and Development of Automatic Fish Feeder System Using PIC Microcontroller*. Faculty of Electrical Engineering, Universiti Teknologi MARA Malaysia, 2012.

Othman, K. & Kamal, M. (2009). *System Identification of Discrete Model for DC Motor Positioning.* Proceedings of the 8th WSEAS International Conference on Circuits, systems, electronics, control & signal processing. pp 212-216.

Patil, A. & More, S. (2014). *Mathematical Modelling of Physical System.* IOSR Journal of Electrical and Electronics Engineering, 9(3), pp 57-64.

Patrick, H.G., Baniqued, Martin J.C., Castro, D. & Chael T.T. (2009). *Microcontroller Based Fish Feede*r. Luzano.

Rabbani, M. J., Hussain, K., Khan, A. U. R. & Ali, A. (2013). *Model Identification and Validation for a Heating System Using Matlab System Identification Toolbox*. IOP Conference Series: Materials Science and Engineering, 51(1).

Rachad, S., Nsiri, B. & Bensassi B. (2015). *System identification of inventory system using ARX and ARMAX models.* Int. J. Control Autom., vol. 8, no. 12, pp. 283–294, 2015.

Reddy, M. L., Reddy, M. R. & Reddy, V. C. V.. (2012). *Optimal Power Flow using Particle Swarm Optimization.* Vol. 4, no. 1, pp. 116–124, 2012.

Saad, M. Karimi (1998). *Adaptive control.* Lozano, , 1998 July, 845-846

Salleh, S., Tokhi, M.O., Member, S., Julai, S., Mohamad, M. & Latiff, I.A. (2009). "*PSO-Based Parametric Modelling Of a Thin Plate Structure*," pp. 0–5, 2009.

Samin, R. E., Jie, L. M. & Zawawi, M. A. (2011). *PID implementation of heating tank in mini automation plant using programmable logic controller (PLC)*. InECCE 2011 - Int. Conf. Electr. Control Comput. Eng., pp. 515–519, 2011.

Shi, Y. & Eberhart R. (1998a). *A modified particle swarm optimizer*. in Proc. IEEE Int. Conf. Evol. Comput., Anchorage, AK, May 1998, pp. 69–73.

Shi, Y. & Eberhart R. (1998b). *Parameter selection in particle swarm optimization.* Proceedings of the 1998 Annual Conference on Evolutionary Programming. San Diego: MIT Press; 1998.

Shaari, M.F., Zulkefly, M.E.I., Wahab, M.S. & Esa, F. (2011). *Aerial fish feeding system*. IEEE Int Conf Mechatronics Autom ICMA 2011. 2011;2135–40.

Subasinghe, S. (2007). Vannamei, tilapia, catfish…what next? Infofish International, 3. Kuala Lumpur.

Suganya, S., Rajinikanth, V. & Deepa, P. (2017). *Design Of Pid Controller For Chemical Process- Heuristic.* Int. Third On, Conf. Technol. Sci., Pp. 2–5, 2017.

Takao, K. M., T. & Yamamoto, Y. (1990). *Dead Beat Control of Three Phase PWM Inverte*. IEEE January 1990.

Tekwani, P. N., Kanchan, R. S., Sanjay, L. & Gopakumar, K. (2006). *Switching Frequency Variation Control in Hysteresis PWM Controller for IM Drives Using Variable Parabolic Bands for Current Error Space Phasor*. July 9-12,2006.

Vadim, U. (2009). *Sliding mode control*. Control System, Robotics and Automation, (2009) Vol. 13.

Wang, Q. J. (1997). Using Zulkefly, M.E.I. (2010). *Development of PLC controled Ariel Fish Feeding System.* Bachelor Degree Thesis in Mechanical Engineering, Universiti Tun Hussien Onn Malaysia 2010. Genetic Algorithms to Optimise Model Paramters. Environmental Modelling & Software, 12(1), 27-34.

William, J. P. (2008), *A Concise Introduction to MATLAB*, Mc Graw Hill International Edition.

Yadav, V. & Tayal, V. K. (2018). *Optimal Controller Design for a DC Motor using PID Tuner*. Int. Conf. Power Energy, Environ. Intell. Control, pp. 442–445, 2018.

Yeoh, S. J., Taip, F. S., Endan, J. and Talib, T. A. (2010). *Development of Automatic Feeding Machine for Aquaculture Industry*. University Putra Malaysia, Selangor, Malaysia.

Yusoff, Z.M. & Muhammad, Z., (2012) *“ARX Modelling for Down-Flowing Steam Distillation System,”* 2012 IEEE 8th Int. Colloq. Signal Process. its Appl., pp. 485–490, 2012.

Zadeh, L. A. (1962). *From circuit theory to system theory*. Proc. of the IRE, vol. 50, no. 5, May 1962, pp. 856-865.

Zhang, Q., Wu, S. & Li, Q. (2016). *A PSO identification algorithm for temperature adaptive adjustment system*. IEEE Int. Conf. Ind. Eng. Eng. Manag., vol. 2016–Janua, pp. 752–755, 2016.